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64 Articles exhibiting a blood-compatible surface layer and process for providing articles with such a surface layer.

57 Article exhibiting at least one surface of glass, metal or hydrophobic polymer coated with blood-compatible surface layer, in which the biocompatible surface layer consists of an adsorbed hydrophobized water-soluble polymer. Process for providing said articles by adsorption of hydrophobized water-soluble polymer. Use of such a substrate material coated with said surface layer for manufacture of medical articles having a blood-compatible surface.

**Description****Articles exhibiting a blood-compatible surface layer and process for providing articles with such a surface layer**5 Field of the invention

The present invention relates to articles exhibiting a blood-compatible surface layer and methods for providing such articles with such a surface layer and in particular for providing articles useful within medicine. More particularly, the invention relates to articles exhibiting at least one surface of glass, metal or a hydrophobic polymer coated with a blood-compatible surface layer and processes for providing articles exhibiting at least one surface of glass, metal or a hydrophobic polymer with a coating of a blood-compatible surface layer, as well as the use of substrate material of glass, metal or hydrophobic polymer, coated with the surface layer of an adsorbed hydrophobized water-soluble polymer preferably a non-protein for manufacture of a medical article having a blood-compatible surface.

15 Background of the invention

Prior art technique to provide articles useful in medicine with a blood-compatible surface layer often comprises an alteration in the surface energy of the material. An improvement in the properties of various materials has been obtained by modifying the surface layers either to a more hydrophobic character or to a more hydrophilic character. Hydrophobization of the surface layer, for instance by the methylation of a glass surface, results in a decrease in the effectiveness of the surface activated coagulation system of the blood. However, proteins such as fibrinogen are bound comparatively firmly to such surface and to this protein layer certain cells, the thrombocytes, can be bound and activated whereafter coagulation is started even though it proceeds slowly. Hydrophilic surfaces, e.g. hydrolysed nylon or oxidized aluminium, have presented reduced binding of cells but the surface activated coagulation system is not prevented at these surfaces. The use of these surfaces in contact with blood thus implies the addition of anti-coagulants, for instance heparin to the blood.

Another prior art surface treatment technique for preventing coagulation comprises binding of anticoagulants into the surface layer. Heparin has primarily been used with this technique. Heparin is a hexoseaminehexuronic acid polysaccharide which is sulphatized and has acid properties, i.e. heparin is an organic acid. According to DE-A-21 54 542 articles of an organic thermoplastic resin is first impregnated with an amino-silane coupling agent and the article thus treated is then reacted with an acid solution of heparin salt to the binding of heparin in the surface layer by means of ionic bonds. Surfaces thus treated with heparin have proved to reduce the coagulation reaction. A considerable disadvantage of these surfaces, however, is that the heparin treatment does not prevent the adherence of thrombocytes, which is a great problem in, for instance, heart-lung machines.

On the 10th Annual Meeting of the Society for Biomaterials (Washington D.C. April 27, 1984) was described that polyethylenglycol surfaces on quartz minimize protein adsorption. Procedures for covalent binding of polyethylenglycol to surfaces have previously been described, e.g. in W086/02087. Polyon complexes formed between a cationic and an anionic cellulose derivative have also been found to have good blood-compatibilities (Ito, H. et.al., J. Appl. Polym. Sci., Vol.32 (1986) 3413). Methods of covalent binding of water-soluble polymers to surfaces have also been described, e.g. in EP 166 998.

It is known that water-binding gels, for instance polyhydroxyalkylmethacrylate, reduce the adsorption of proteins and present a low adhesiveness to cells (Hoffman et al., Ann. N.Y. Acad. Sci., Vol. 283 (1977)372). These properties are considered to be due to the fact that gels containing water give a low surface energy in the interface to the blood. The prior art technique for manufacturing of water-binding gels, however, is impaired by disadvantages such as complicated preparation technique and incomplete polymerization, which results in leakage of toxic monomers. A gel-like mixture of saccharose and glucose included in a matrix of the polysaccharide dextran or dextrin is used in accordance with previously known technique as a tube for the connection of blood-vessels. This mixture should have the effect that no toxicity to the patient occurs that the implantate is dissolved in the blood after some time. It is known that the neutral polysaccharide dextran is miscible with blood without provoking any coagulation reaction. Dextran has been used as a surface coating on glass, aluminium and silicon rubber, and has been shown to reduce blood coagulation during blood contact with these surfaces as described in W083/03977.

The adhesion of blood components to surfaces in contact with blood could be decreased by preadsorption of albumin to hydrophobic surfaces (Mosher, D.F in: Interaction of blood with natural and artificial surfaces, Ed. Salzman, E.W, Dekker Inc 1981). The adsorbed albumin does not form a stable coating, but is desorbed during contact with blood and coagulation is induced although at a lower rate.

60 Disclosure of the invention

The object of the present invention is to provide articles useful within medicine with a blood-compatible

surface layer. This means, for articles intended for use in contact with blood, that the article which is alien to the blood is treated in such a way that it does not induce coagulation or formation of thromboses.

The present invention affords technique for the surface treatment of material important for medical technology, such as glass, metal and hydrophobic polymers (e.g. polytetrafluoroethylene (PTFE)).

The article according to the invention which exhibits at least one surface of glass, metal or hydrophobic polymer coated with a blood-compatible surface layer, is characterized in that the blood-compatible surface layer consists of an adsorbed hydrophobized water-soluble polymer. 5

The process according to the invention for providing articles exhibiting at least one surface of glass, metal or hydrophobic coated with blood-compatible surface layer, is characterized in that said substrate surface of the article, after hydrophobization when required, is exposed to a hydrophobized water-soluble polymer, which adsorbs, to said substrate surface. 10

The substrate surface has to be hydrophobic before coating. For metals or metal oxides this can be achieved by methylization with silanes.

The polymers used in the present invention are hydrophobized derivatives of water-soluble polymers. This means that the polymers used are limited soluble in water depending on the degree of hydrophobization. Examples of possible polymers that could be hydrophobized and used as surface coating polymers are mentioned below. 15

#### Natural water-soluble polymers 20

- 1) Starches, especially derivatives such as ethers
  - 2) Celluloses, especially cellulose ethers
  - 3) Other polysaccharides
- alginate acid, gum arabic, gum guar, gum tragacanth, tannin, tamarind and lignin 25

#### Synthetic water-soluble polymers

- 1) PVA  
polyvinyl alcohol 30
- 2) Polyethylene oxides  
polyethylene oxide, polyethylene glycol
- 3) Acrylates  
sodium polyacrylate
- 4) Maleic anhydride polymers  
methyl vinyl ether-maleic anhydride copolymers 35
- 5) Phthalates  
polyhydroxy ethyl phthalates
- 6) Water-soluble polyesters  
polydimethylol propionate
- 7) Ketone aldehyde resins 40  
methyl isopropyl ketone formaldehyde resin
- 8) Acrylamides  
polyacrylamide
- 9) Polyvinyl pyrrolidone 45
- PVP
- 10) water-soluble nylon

The water-soluble polymer used in this invention is a hydrophobized derivative of one of these polymers and it is characterized by the property of the ability to adsorb at hydrophobic surfaces. The hydrophobization of the polymer can be performed by binding of hydrocarbons to the polymer backbone. Examples of such hydrocarbons are alkyl-groups, benzyl-groups or alkenyl-groups. The hydrophobization renders the polymer partly insoluble in water with a flocculation above a certain temperature or above a certain ionic strength. 50

The substrate surface is exposed to a solution of the polymer at a temperature below flocculation and at a salt concentration below flocculation. The hydrophobized polymers adsorb strongly to hydrophobic surfaces. Preferred polymers should have a flocculation temperature of about 35-40°C.

The treated surface proves biologically inert and surfaces treated in this way give reduced adsorption of proteins, adherence of cells and coagulation. The adsorbed polymer is not exchanged by plasma proteins. 55

The process according to the present invention can be applied within many fields. Thus, in heart-lung machines there are used many details which are made of aluminium which can easily be treated by methyl-silane to get a hydrophobic surface.

The process according to the present invention is ideally suited for treatment of venous catheters. These are often manufactured in PTFE and this material is normally not blood compatible. For this material it is also difficult to find appropriate processes for covalent coupling of hydrophilic polymers. 60

The invention may also be applied in other connections, for instance, for treatment of articles of hydrophobic plastics for sampling and/or storage of blood.

The invention will in the following be illustrated by a working example but is not limited thereto and hence 65

modifications are of course conceivable within the limits of the claims.

#### Working example

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#### Coating procedure

- a) The polymer is purified and isolated by repeated heat flocculation and centrifugation.  
 b) A polytetrafluoroethylene-tube (teflon), diameter 3 mm, and a polyurethane-tube, diameter 3 mm, were  
 10 immersed in a solution of ethyl-hydroxyethyl-cellulose (EHEC, 1 g/l, prepared according to US 3,926,951) in distilled water for 20 hours in room temperature. The tubes were rinsed in saline for 1 minute.

#### Experimental tests

- 15 Two different tests were performed. Incubation with a solution of fibrinogen at high concentration was performed in order to detect exchange reactions between the polymer and plasma protein. Incubation with whole blood followed by measurement of released thromboglobulin was used to measure the stability of the polymer coating and the activation of platelets at the surface.

#### 20 Fibrinogen adsorption

- a) Coated and non-coated tubes were incubated in a solution of human fibrinogen (1 g/l) in saline for 30 minutes at room temperature.  
 b) The tubes were rinsed in saline for 10 seconds.  
 25 c) Incubation in anti-fibrinogen antiserum diluted 1:1000 for 1 hour at room temperature.  
 d) Incubation with peroxidase-conjugated anti-antibodies for 30 minutes.  
 e) Incubation in a solution of orthophenylenediamine (0.5 g/l) and 0.01 %  $H_2O_2$  in 0.1 M citrate buffer, pH=4.5.  
 f) Addition of 2 M  $H_2SO_4$  and reading of absorbance at  $\lambda=450$  nm.

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#### Blood-compatibility test

- a) Venous blood (18 ml) was tapped from a healthy donor into 2.0 ml of a solution of hirudin in saline (500 IE /ml) (Hirudin is a thrombin inactivator).  
 35 b) The blood was filled into coated and non-coated tubes and allowed to incubate for 2 hours at room temperature.  
 c) 1 ml of blood was drawn into a syringe containing 0.2 ml diatube® and the mixture was centrifugated at 5000 g for 30 minutes at +3°C.  
 d) The supernatant was collected and the amount of  $\beta$ -thromboglobuline using a commercial kit  
 40 (Diagnostica Stago).

#### Results

- The results of the tests above are presented in table I and II. Table I shows that the amount of fibrinogen  
 45 adsorbed to the tubes is reduced by the coating with ethyl-hydroxyethyl-cellulose. Table II shows that the amount of  $\beta$ -thromboglobuline released from the platelets during incubation with blood is also reduced by the coating with ethyl-hydroxyethyl-cellulose.

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TABLE IAmount of surface adsorbed fibrinogen as measured by the ELISA

	teflon	poly- urethane	poly- propene	latex rubber	poly- vinyl	silicone rubber	poly- styrene
uncoated	0.953	0.868	0.406	0.220	0.439	0.794	0.634
EHEC (35°C)*	0.242	0.188	0.304	0.110	0.268	0.246	0.005
EHEC (45°C)*	0.969	0.420	0.308	0.153	0.274	0.560	0.016
Klucel™ ** (<RT)*	1.042	0.922	0.434	0.131	0.203	0.722	

Footnotes: \* flocculation temperature of the polymer in distilled water.  
 \*\* propyl-hydroxypropylcellulose

TABLE IIAmount of  $\beta$ -thromboglobuline released as measured by the ELISA

	teflon	polyurethane
uncoated	1.38	1.67
EHEC (35°C)	0.44	0.85

## Claims

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1. Article exhibiting at least one hydrophobic surface of glass, metal or a hydrophobic polymer coated with blood-compatible surface layer, characterized in that the blood-compatible surface layer consists of an adsorbed hydrophobized water-soluble polymer.

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2. Article according to claim 1 in which the water-soluble polymer is a non-protein.

3. Article according to claim 2 in which the water-soluble polymer is hydrophobized neutral polysaccharide.

4. Article according to claim 3 in which the polysaccharide is hydrophobized cellulose.

5. Article according to claims 3-4 in which the polysaccharide is alkylated cellulose.

6. Article according to claim 4 in which the polysaccharide is ethyl-hydroxyethyl-cellulose.

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7. Article according to claims 1-6 in which the water-soluble polymer has a flocculation temperature of about 35-40° C.

8. Article according to claims 1-7, characterized in that the hydrophobic polymer surface is polytetrafluoroethylene.

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9. Article according to claims 1-8, characterized in that it is a catheter, tube or a device for sampling and/or storage of blood.

10. Article according to claims 1-7, characterized in that it is a heart-lung machine exhibiting at least one hydrophobic aluminum surface with a coating of blood-compatible surface layer.

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11. Process for providing articles exhibiting at least one hydrophobic surface of glass, metal or a hydrophobic polymer with a coating of a blood-compatible surface layer, characterized in that said surface of the article, after hydrophobization when required, is exposed to a hydrophobized water-soluble polymer which adsorbs to said hydrophobic surface of the substrate.

12. Use of a substrate material of glass, metal or hydrophobic polymer coated with a surface layer consisting of an adsorbed hydrophobized water soluble polymer for manufacture of a medical article having a blood compatible surface.

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European Patent  
Office

# EUROPEAN SEARCH REPORT

Application number

EP 88850268.9

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 4)
X	CA - A - 1 208 557 (G.B. MARKS et al.) Page 5 ---	1-12	A 61 L 33/00
X	Chemical Abstracts, Vol. 102 (1985) abstract No. 67 368, Kenkyo Hokoku-Sen'i Kobunshi Zairyo Kenkyusho, 1982, (131) 11-22 (Jap) ---	1-12	
X	Derwent's Abstract No. 87-239975/34 JP - A - 62164468 (DAICEL CHEM IND KK) 21 July 1987 ---	1-4, 7-12	
X	Derwent's Abstract No. 87-105705/15 JP - A - 62053666 (MITSUBISHI RAYON KK) 9 March 1987 ---	1-2, 7-12	
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A	Journal of Bioengineering, Vol. 2, p. 241-249, 1978, J.M. Courtney et al.: "Polymer Modification and Blood Compatibility". -----	1-12	
The present search report has been drawn up for all claims			
Place of search STOCKHOLM		Date of completion of the search 26-10-1988	Examiner JONSSON H.C
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date O : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			